Heliyon 8 (2022) e12309

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Scenario modelling of proxy system in the context of Malaysian food flow management

Latifah Abdul Ghani [a,*], Noor Zalina Mahmood [b], Roslina Ismail [a], Siti Aisyah Sa'at [a], Nora'aini Ali [c], Siti Aishah Mohd Zakuan [a]

[a] Faculty of Business, Economic and Social Development, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia
[b] Institute of Biological Sciences, Faculty of Science, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
[c] Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia

ARTICLE INFO

Keywords:
Food flow
Material flow analysis (MFA)
Local food system
Malaysia
Sustainable development goals

ABSTRACT

The research on food flow network is unpredictable as the approaches employed are more targeted at specific study points, often excluding spatial and temporal changes. The research questions must still address why and how food flow moves in the entire supply chain system. This study aims to investigate the movement of food flow using national statistics, comprising of four main subsystems: agriculture, nutrition, waste, wastewater management, and the environment by using the Material Flow Analysis (MFA) approach. Comprehensive research using primary and secondary data including literature reviews have successfully bridged the knowledge gap on food supply chain management in Malaysia. This article provides new contributions through the considerations of food safety and the opportunity to understand flow issues that are connected to hotspots, closed flow, and economic circulars. Additionally, this study acts as a simple guide for policymakers to manage the imbalances of food supply in certain areas. From the perspective of food waste management, several important strategies were successfully formulated to combat the leakage of food waste flow and financial burden while highlighting the need for local social actors' involvement to fulfil Malaysia's agenda of Sustainable Development Goals.

1. Introduction

Food is access to quality and quantity for supplier-consumer, food safety and in particular, sustainable food resource management which is essential to the world economic circular and Sustainable Development Goals (SDG) 12.3 agenda (Irmeline et al., 2020; Laura et al., 2021). The world's population will continue to increase in the coming years by an average of 1.1% per year with an expectation of reaching 9.7 billion people by 2050 (Emiko and Will, 2020). This event will be characterised by a projected increase in global food demand of almost 102% between 2009 and 2050 (Amy et al., 2021). This will heighten the role of the agricultural and manufacturing sectors as key input providers, as well increase food subsistence, domestic and global buffer stocks and food items such as livestock, vegetables, animal or vegetable fats, oils, waxes, dairy, eggs, abandoned land expansion and so on (Alias et al., 2014). Malaysia was ranked 28th in the Global Food Safety Index (GFSI) in 2019 (RM 43.5 billion for Malaysia's global agricultural trade), producer (10% of the country's total food processing sector), importer (one-fourth or 24% of the total food supply in the year 2020), exporter (7.4% of agricultural products equivalent to RM 6.6 billion in the year 2020) and consumer (average food disposal is estimated at 1.64 kg (kg) per day per individual) (Bank Negara, 2020; Department of Statistics Malaysia, 2020). These estimates highlight the substantial pressure imposed on the Government to manage the resources of the national food chain.

Apart from the food availability, food access, food stability and usage of food, the increase in imported food products which was driven by the inefficiency of agricultural products in the local market is one example of the problems related to national food (Regina et al., 2020). For instance, Malaysia's paddy production is a strategic national priority commodity and is usually used as the staple food for Malaysians. In recent years, subsistence rates achievement and low rice production have been linked to factors of increase in production cost and imported food prices, global food shortages, increase in oil prices, increasing world population, climate changes, environmental crises, plant diseases, and insect attacks that have disrupted national rice stockpile (Radin et al., 2020; Adnan and Nordin, 2021). From the aspect of national food flow research, the capacity of the subsistence food commodity including grain, fruits, industrial crop, livestock commodities and others should be given more

* Corresponding author.
E-mail address: latifah.ghani@umt.edu.my (L.A. Ghani).

https://doi.org/10.1016/j.heliyon.2022.e12309
Received 21 February 2022; Received in revised form 10 March 2022; Accepted 5 December 2022

attention which is visionary enough to finally support the long-term national agricultural safety policy.

In Malaysia, the continuity of food safety is one of the main issues to consider in achieving a sustainable food system. Driven by economic growth, the scale of food waste from the categories of kitchen waste, leftovers, expired and contaminated food has increased by 15 times in four years (Jereme et al., 2016). It is estimated that as much as 15,000 thousand tonnes of food per day is disposed of in the landfills, which has increased the emission of methane gas as much as 47% and other greenhouse gases as much as 25% higher compared to the emission of carbon monoxide gas that ends up at the garbage disposal area (M.F.M et al., 2010). The loss of food from farm to fork level has shifted some pressure from the food chain source to the system of potential waste recoveries like soil conditioner, compost manure, and power generation, thereby adding value to food products and the shift of providing food to the system that needs it. Nevertheless, a clear challenge arising from this momentum of transition is to keep track of unintentional issues triggered by the diversity of food flows according to different subsystems. Furthermore, higher frequency towards the demands and food purchase during the COVID-19 pandemic has added disruptive input and complexity to the food flow chain. For example, a reduction in the production of local agricultural products may occur in some resource supply chains that are heavily dependent on raw materials that need to be imported from foreign countries (Heikal et al., 2020). Therefore, the globalisation wave in food-water-energy systems has become an important factor and its efficiency should be investigated in Malaysia's food flow management scenario.

Material Flow Analysis (MFA) is considered an effective and widely used method to measure and visualise the material and stock-flow pattern in certain production systems. A qualitative review of the previous literature using the MFA approach has focused on different scenarios on a national scale, such as waste management (Haikal and Marlia, 2021; Ghani, 2021), urbanisation (Muhd Adib et al., 2021; Shafie et al., 2020), agriculture (Ahmad et al., 2019; Latifah et al., 2019), and nutrient and metal management (Ghani, 2018; Nur Rahishahanim and Norashikin, 2021). However, MFA research which is specifically focused on food flow systems is still limited to subsystem level (e.g agriculture, wastewater management), temporal scale (e.g; year, multi-years) geography (e.g urban-rural, region, state), and type of sampling (e.g; probability and non-probability sampling) not excluding research conceptualising sensitivity flow, uncertainty intervals, and multiple scenarios for future potentials.

Furthermore, the movement of food destinations can be mapped differently according to the contribution from the various sector levels: primary production, manufacturing, retail distribution, food facilities, household consumption, and food waste disposal (Iona et al., 2021). Preliminary case studies in the context of rice, sugar and egg consumption management in Selangor and Kuala Lumpur found that population growth factors, demography and nutritional patterns strongly influence the production rate, usage and recovery of food end products in the system chain (Shafie et al., 2016). Therefore, MFA techniques need to be expanded to be more suitable for the food chain instead of being a complex, multiple and comprehensive system at the national level. A recent literature review by Sulaiman et al. (2021), (Brunner and Rechberger., 2016) recommended that apart from household groups, the percentage of guaranteed availability of continuous food flow for vulnerable groups (i.e., immigrants, refugees, the sick and the disabled (OKU) in Malaysia should be considered as well, rather than focusing on the type of food product. Food waste and surplus, as well as internal and external pressure from the socio-environmental concept of material resources, are typical causes of the growing concerns about food loss in the consumption phase, a more comprehensive understanding of the food flow management strategies across the food management chain is necessary to attain efficient and sustainable food chain in the future.

This study employed the principle of mass balance (Brunner and Rechberger., 2016) to analyse food flow in the entire food supply chain at the national level to fill knowledge gaps and identify hot spot problems in the national food sustainability agenda. The specific research objectives were to (1) develop a food flow accounting sheet in Malaysia based on the available details of the current data and coefficients and (2) identify challenges and problem-solving strategies in food chain management according to local scenarios in Malaysia.

2. Methodology

2.1. Description of study area and system boundaries

The geographical limitations in this study include Peninsular Malaysia, Sabah and Sarawak. All commodities and locations, including forestry and islands, were not targeted due to the unavailability of the lowest statistical data. Moreover, based on the data availability and completeness for the period of one year, the data set for 2019 was considered more meaningful in achieving the research objectives. This research also determined the inflow, outflow and inventory of materials which are considered relevant, comprising of five subsystems from P1 to P5 and environmental boundary (see Figure 1). P1: subsystem based on cultivation, livestock, and plantation; P2: food processing subsystem, P3: food consumption subsystem by the household sector and the related consumers; P4: food waste management subsystem, and P5; wastewater management subsystem. P1; Subsystem based on Symbol 'P in the box (or level)' and 'f' each signifying the process (or sector or stock) for 'P', and the network of the flow of material movement either inwardly and outwardly between the subsystem for 'f' as the detailed flow is explained and marked in Figure 1. Stock was defined as the net difference between material mass for the total inflow and outflow and, sometimes it is perceived as 'storage' for a certain period in a particular research system. The principle of mass balance is "Input = Output + Stock".

2.2. Data collection

The mass flow of the material marks the onset of data collection in this study, which has been differentiated into two categories of important information: the flow and the coefficient (or concentration) of the material. To facilitate the review and evaluation of the ethical commitment of social science research, this study has obtained ethical approval by the Committee of Universiti Malaysia Terengganu and the participants have confirmed it through a consent sheet provided to them. The data collection approach adopted entailed the literature review, face-to-face interviews, followed by household, departmental, experts and field research survey questionnaires. Most of the statistical data on agricultural, trade and nutrition commodities were obtained from the database of the Statistics Department of Malaysia and supported with census information, bulletins, literature reviews and official statistical reports from 13 states in Malaysia. The national organic waste data was referenced from the development plan report while the statistical reports from Indah Water Konsortium Sdn Bhd (IWK) and the Department of Environment (DOE) were used to collect information regarding the strategic core of food waste management for the industrial, commercial and the institutional sectors (from 2016 to 2026) (MHLG, 2021), the rate of treated wastewater discharge, wastewater discharge, and sludge flow from industrial pollution (MOA, 2017). Information on the ratios and coefficient of production, use and discharge of food wastes, human wastes, livestock manure, animal feed composition and effluent were based on local literature research and supported by interviews by experts in related fields. Detailed information on the above description is presented in Table 1.

2.3. Food flow calculation

As shown in Figure 1, the measurement of food flow according to the flow structure scheme follows five important subsystems (P1 to P5, including O1 and E) by taking into account the relevance of five calculation factors: rations factor (or percentage), content factor (or

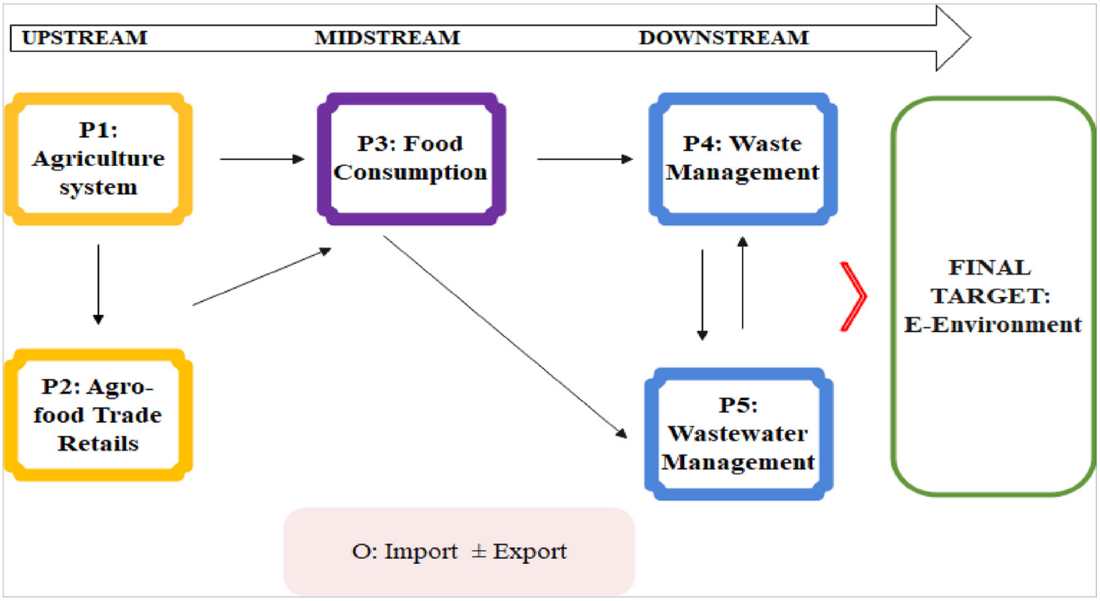

Figure 1. The overall picture of the food flow structure scheme in Malaysia. (P1) Agriculture production subsystem; (P2) Food product trade subsystem; (P3) Food usage subsystem; (P4) Waste management subsystem; (P5) Wastewater management subsystem; (E) Environmental system and (O) Import and export of food product. The connecting arrows indicate the signal of direction for material flow.

coefficient), consumption factor per capita per person, mass balance factor, and hybrid factor. In this case, the use of the MFA method successfully classified 42 quantitative equations linking 84 mutually compliant flows of the mass equilibrium of the whole system, as listed in Table 2. Some examples of the equations developed based on the content factors, ratio factors, and individual factors were used to calculate the total production of livestock products, crops, animal feed, food product processing, raw food consumption, food waste, garbage, and household sewage that are discharged to the sewers. Additionally, the use of hybrid factors involving a combination of other factors and mass equilibrium factors focused more on the calculation of material accumulation and mixing of external flows, lost flows or redirected flows into subsystems, such as compost flow, sewage recycling flow, and others.

2.4. Proxy model scenario construction

In this study, an alternative of MFA system framework construction was employed to obtain flow balance by attempting to include buffer system and different scenario testing evaluations, covering material, time and space scale, which ultimately contributes to system coordination and strengthens study planning concept in subsequent research. Therefore, five scenarios based on proxy system construction were considered as shown in Figure 2, consisting of Fa, Fb, Fc, Fd, and Fe scenarios.

The first scenario is interpreted as a Fa-Modeling system, which is assumed not to experience any alterations in the flow percentage rate as presented in Figure 1. The second scenario is that of the Fb-proxy system usage at an upstream level. This scenario assumes a 30%–60% increase in efficiency of community crop production, livestock, dairy, feed products at the P1 and P2 subsystem levels to meet price supply and excess domestic demand, thus reducing imported food products from foreign countries. The third scenario refers to the Fc-proxy system usage at intermediate levels, which assumes population growth and changes in dietary patterns by local consumers, including foreign nationals were used as the basis for the calculations in P3 as described by Maryegli et al. (2021). Scenario Fd refers to the downstream level that includes the stages of disposal and treatment of food waste (P4), wastewater (P5), and Environment (E). The last scenario refers to the Fe-Consolidation of Scenario Fb, Fc and Fd onto Scenario Fa, which was constructed according to the flow diversion adaption at the P4 and P5 stages from entering into the environment. Furthermore, the efficiency of food waste management, Recycle, Reuse, Reduce (3R), education and others were enhanced by assuming some aspects of improvements, such as the use of integrated treatment technology for sludge. For instance, the assumption is that 30% of illegally disposed waste will be returned to landfills (Ahmad et al., 2019; Chen et al., 2021).

2.5. Uncertainty analysis

Uncertainty analysis was performed using the uncertainty interval method by (Hedbrandt and Sörme, 2001) and Danius (2002) to examine the accuracy and reliability of input data quality reporting, the standard deviation for food statistics, food waste concentration variations and various other data sources (including the source of government, literature highlights, alternative calculations and field experiments). The 'reliability check' method is used in the MFA method to identify data variation, flow data loss, material coefficient variation, and mathematical calculation error, thereby assisting the research to obtain appropriate and accurate coordination and balancing of information (Schwab and Rechberger, 2018; Paritosh et al., 2020; Patrício et al., 2015). Uncertainty over each unknown food flow or consumable product is considered to be linearly proportional to the known food inflow (James and Cynthia 2013). Three important steps were considered in the quantification of food flow uncertainty in this study. The first step entailed identifying data ownership according to source reference, data quality characterisation, and data specialisation as presented in Table 3. The second step involves the calculation of the upper and lower intervals according to the appropriate uncertainty factor using Eqs. (1) and (2) (Danius and Von Malmborg, 2002) as shown below:

$$P_{a\times b} = P_a \times P_b$$

$$C_{a\times b} = 1 + \sqrt{(C_a - 1)^2 + (C_b - 1)^2} \tag{1}$$

$$P_{a+b} = P_a + P_b$$

$$C_{a+b} = 1 + \sqrt{[m_a \times (C_a - 1)]^2 + [m_b \times (C_b - 1)]^2}$$

Table 1. Measurements of subsystems and data sources.

Subsystem	Data collection details	Literature sources
Agriculture	Animal production, crop production, water loss lost from agricultural land, fertiliser imports, agricultural land area	- Department of Agriculture Malaysia, Ministry of Agriculture and Food Industries (MAFI), MARDI, : http://www.doa.gov.my : https://www.mafi.gov.my/home - Interview with farmers, agricultural offices - Biomass waste used for composting; Composting mass balance
Agro-Food Trade Processing	Net import of animal feed, export of human food, animal products, crop products etc.	- Market mass balance - Interview with sellers in markets, farmers
Human consumption	- Changes in human diet, per capita food intake limits: meat, milk, eggs, etc. -Population, water and food consumption, human waste and other wastewater discharges - Food imported	- Literature on population and household sensus: Department of Statistics Malaysia - Food and Agriculture Data (FAOSTAT) - Population that can access to sanitation - Literature of Malaysia population and housing census
Wastewater management	- Direct excrement (dirt and food waste dumped into sewers; blackwater), indirect excrement (disposal/leakage of other feces; gray water), - Sludge for recycling, compost or others. - Fluent effluent to water body, biosolid application to landfill. - Quantity of excreta, oil and wastewater from other food sources	- Coefficient of wastewater transfer from literature sources. Examples; Leachate: Literature Chin et al. (2020), Excreta, urine: wet weight (Sallehuddin et al., 2021; Stanisavljevic and Brunner, 2014). - Survey questionnaires from households - The literature about sewage sampling and lab analysis from Department of Drainage, SPAN, IWK and Department of Statistics: 1) mass effluent of wastewater treatment plant; 2) mass effluent wastewater to drainage; mass balance of septic tank 3) mass domestic wastewater 4) Wastewater to drainage and surface water to environment.
Waste management	Malaysia's annual waste statistics crop waste, animal product waste disposed of landfills, food waste incinerated, and percentage of solid organic waste collected; market solid waste recovery option rate.	- Agro-food stock-mass balance - Human excreta in Malaysia literature: Latifah et al. (2019) - Illegal solid waste dumping; Mass balance of collection/sorting - Moisture content in food garbage; local researcher data (2020) - Percentage of organic waste in municipal solid waste; Ministry of Housing and Local Government Malaysia - Percentage of organic waste in market; Literature; Yaacob et al. (2019) - Solid waste collected by the municipality; Solid Waste Management and Public Cleansing Corporation (SWCorp) (2020).

Table 2. The subsystem process and flows involved.

Process	Flow name	Source process	Destination Process	Food flow [kt/year]
P1: Agriculture				
Input				
P1-AG	f1: Fertilizer use		P1-AG,Agriculture	1,612 ± 10
P1-AG	f2: Imported feed		P1-AG,Agriculture	4,300 ± 3
P1-AG	f6: Animal feed	P2-FT, Food Trade & Commerce	P1-AG,Agriculture	4,500 ± 4
P1-AG	f7: Seed	P2-FT, Food Trade & Commerce	P1-AG,Agriculture	87,678 ± 10
P1-AG	f13: Compost to agriculture	P3-HC, Human Consumption	P1-AG,Agriculture	1,000 ± 7
P1-AG	f16: Recycled effluent	P5-WwM, Wastewater Management	P1-AG,Agriculture	1 ± 15
P1-AG	f20: Compost landfill	P4-WM, Waste Management	P1-AG,Agriculture	170 ± 7
Output				
P1-AG	f4: Animal Product	P1-AG,Agriculture	P2-FT, Food Trade & Commerce	283,540 ± 5
P1-AG	f5: Crop Products	P1-AG,Agriculture	P2-FT, Food Trade & Commerce	4,790 ± 5
P1-AG	f28: Manure sold to market	P1-AG,Agriculture	P2-FT, Food Trade & Commerce	251,473 ± 10
P1-AG	f29: Manure losses	P1-AG,Agriculture	E, The Environment bodies	251,473 ± 13
P2: Food Trade & Commerce				
Input				
P2-FT	f4: Animal Product	P1-AG,Agriculture	P2-FT, Food Trade & Commerce	283,540 ± 5
P2-FT	f5: Crop Products	P1-AG,Agriculture	P2-FT, Food Trade & Commerce	4,790 ± 5
P2-FT	f18: Aquatic feed		P2-FT, Food Trade & Commerce	1,867 ± 3
P2-FT	f21: Reused waste	P4-WM, Waste Management	P2-FT, Food Trade & Commerce	57 ± 7
P2-FT	f3: Imported animal food		P2-FT, Food Trade & Commerce	1,882 ± 7
P2-FT	f26: Others Food Imported		P2-FT, Food Trade & Commerce	18,334 ± 7
P2-FT	f28: Manure sold to market	P1-AG,Agriculture	P2-FT, Food Trade & Commerce	251,473 ± 10
Output				
P2-FT	f6: Animal feed	P2-FT, Food Trade & Commerce	P1-AG,Agriculture	4,500 ± 4
P2-FT	f7: Seed	P2-FT, Food Trade & Commerce	P1-AG,Agriculture	87,678 ± 10
P2-FT	f8: Food product	P2-FT, Food Trade & Commerce	P3-HC, Human Consumption	18,184 ± 7

(continued on next page)

Table 2 (*continued*)

Process	Flow name	Source process	Destination Process	Food flow [kt/year]
P1: Agriculture				
P2-FT	f12: Food discharges_1	P2-FT, Food Trade & Commerce	E-The Environment bodies	128,293 ± 15
P2-FT	f19: Aquatic Product	P2-FT, Food Trade & Commerce	P3-HC, Human Consumption	1,819 ± 5
P2-FT	f23: Processing waste discard	P2-FT, Food Trade & Commerce	P4-WM, Waste Management	384,878 ± 18
P2-FT	f24: food export	P2-FT, Food Trade & Commerce		28,436 ± 7
P2-FT	f25: Aquatic export	P2-FT, Food Trade & Commerce		276 ± 5
P3: Human Consumption				
Input				
P3-HC	f8: Food product	P2-FT, Food Trade & Commerce	P3-HC, Human Consumption	18,184 ± 7
P3-HC	f19: Aquatic Product	P2-FT, Food Trade & Commerce	P3-HC, Human Consumption	1,819 ± 5
Output				
P3-HC	f10: Food waste discarded	P3-HC, Human Consumption	P4-WM, Waste Management	4,521 ± 5
P3-HC	f13: Compost to agriculture	P3-HC, Human Consumption	P1-AG,Agriculture	1,000 ± 7
P3-HC	f15: Human excreta + sludge	P3-HC, Human Consumption	P5-WwM, Wastewater Management	2,671 ± 10
P4: Waste Management				
Input				
P4-WM	f10: Food waste discarded	P3-HC, Human Consumption	P4-WM, Waste Management	4,521 ± 5
P4-WM	f23: Processing waste discard	P2-FT, Food Trade & Commerce	P4-WM, Waste Management	384,878 ± 18
P4-WM	f27: Sludge discarded	P5-WwM, Wastewater Management	P4-WM, Waste Management	916 ± 12
Output				
P4-WM	f14: Waste to loss	P4-WM, Waste Management	E-The Environment bodies	1,937 ± 10
P4-WM	f20: Compost landfill	P4-WM, Waste Management	P1-AG,Agriculture	170 ± 7
P4-WM	f21: Reused waste	P4-WM, Waste Management	P2-FT, Food Trade & Commerce	57 ± 7
P5: Wastewater Management				
Input				
P5-WwM	f15: Human excreta + sludge	P3-HC, Human Consumption	P5-WwM, Wastewater Management	2,671 ± 10
Output				
P5-WwM	f16: Recycled effluent	P5-WwM, Wastewater Management	P1-AG,Agriculture	1 ± 15
P5-WwM	f17: Unused Ww effluent	P5-WwM, Wastewater Management	E-The Environment bodies	1,755 ± 7
P5-WwM	f27: Sludge discarded	P5-WwM, Wastewater Management	P4-WM, Waste Management	916 ± 12
E: The Environment bodies				
Input				
E	f12: Food discharges_1	P2-FT, Food Trade & Commerce	E-The Environment bodies	128,293 ± 15
E	f14: Waste to loss	P4-WM, Waste Management	E-The Environment bodies	1,937 ± 10
E	f17: Unused Ww effluent	P5-WwM, Wastewater Management	E-The Environment bodies	1,755 ± 7
E	f29: Manure losses	P1-AG,Agriculture	E-The Environment bodies	251,473 ± 13

$$C_{a+b} = 1 + \sqrt{[m_a \times (C_a - 1)]^2 + [m_b \times (C_b - 1)]^2} \Big/ m_a + m_b \tag{2}$$

Where P is the probability value and C is the uncertainty factor.

The last step is to present the overall calculation results according to the zoning coefficents as shown in Table 3.

3. Results and discussion

3.1. Overall food flow results in Malaysia

Figure 3 presents the complete results for the food accounting analysis in Malaysia, showing the flows at the earliest start from the agricultural productivity subsystem and end at the environmental system. Inflow and outflow from the food chain also involved the import and export of raw food commodities, processed food, and by-product food (details are presented in the Supplementary material; Table S1). The medium to high streams quantified from the three main food groups: livestock, cultivation, and fisheries group is expected to provide accurate assumptions for the overall food modelling at the national level. For instance, inflow from the above three groups in the food system amounted to 429 megatonnes per year, which accounted for 39.8% of the total inflows. Erosion soluble flows from agricultural activities, flows from landfill seepage and rainwater from urban systems brought into water bodies were small, hidden and difficult to quantify due to data availability gaps, and their results are discussed in the uncertainty analysis. Overall, a comparison between the total balance of inflow and outflow from other subsystems is presented in the next section to provide quality MFA study results to the relevant support decision-makers.

Figure 4 shows that Malaysia is not the best net importer of food considering the value of the annual food deficit, quantified from total imports minus the exports which amounted to -717 kton/yr in 2019. The overall annual food quantitative flow was 2533 Mt per year, contributing 10% to the overall release of outflow to the environment body in Malaysia (383 Mt in 2019). The comparison made in previous years exposed a significant research gap that needs to be fulfilled in future studies (Ghani, 2021), particularly due to the lack of information regarding efficiency and lost parameters in Malaysia's food trend consumption and local agro-food models. As discussed above, the comparison of the flow equilibrium between each subsystem of the study is required to fulfil the current research gap as shown in Figure 4. The research findings revealed that the annual amount of food inflow and outflow was 1074 Mton/yr and 1742 Mton/yr respectively, encompassing a contribution of 48% and 35% from the P2 subsystem: Agro-Food Trade and P1 subsystem: Agriculture. The lower yield in the food inflow section compared to outflow can be explained in a study that focused on the overall effectiveness or efficiency of a country's food flow

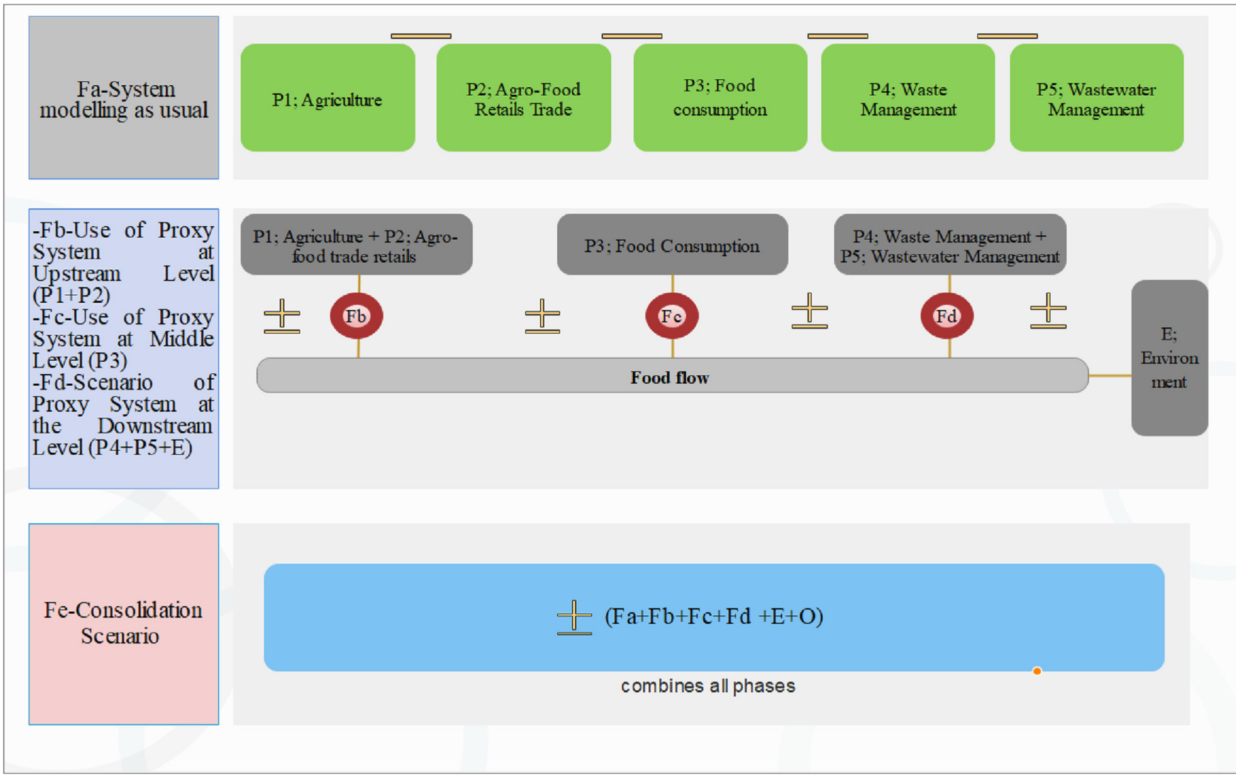

Figure 2. A brief diagram showing the inclusion of four additional scenarios (Fb, Fc, Fd, and Fe) and the retention of one original scenario (Fa) in a proxy system based on food flow management, where "+" indicates an uptrend and "-" indicates a downward trend. Fa describes the original system scenario. Fb, Fc, and Fd are scenarios of the use of proxy systems at the upstream, intermediate, and downstream levels. Fe refers to a combination of proxy system modelling from Fa + Fb + Fc + Fd.

system (Smit et al., 2015). About 60% of the largest quantitative outflow are from farming systems that mostly ended on waste disposal sites, collected as accumulated land stock and ambiguous data which are unrecorded, officially unknown, and being transmitted to the environment system.

3.1.1. Food flow in the agriculture (P1) and trade (P2) subsystems

The study description focuses on two important subsystems (P1 and P2), which accounts for 83% (equivalent to 2,107 Mton/yr) of the total food flow collection within the MFA system. Additionally, three important stages involved are the production, processing, and marketing process of agricultural products. The total amount of annual food input flow into these two subsystems is 661 Mton/yr, whereas the total amount of output flow is 2237 Mton/yr in the form of raw food and prepared food products. Interestingly, the contribution of the import and export transactions on livestock, seeds, fertiliser, aquatic products, and other food products is only by 1% difference, 28 Mton/yr and 29 Mton/yr respectively in the entire P1 and P2 subsystem. Moreover, with the acreage of agricultural land used for short-term crops, long-term crops, and traditional mixed farming amounting to 5.58 million ha in 2019, only 35% of this total land area is used for animal husbandry.

P1 Subsystem: Agriculture refers to the crop, livestock, and plantation production sector for food productivity (Robin et al., 2021), receiving an inflow of food at 99.3 metric tons/yr in this subsystem. Cultivation seeds recorded the highest contribution rate of 88% (Figure 4), supported by the demand for seedlings from palm oil commodities at 82.1 Mton/yr, fruit trees at 2.5 Mton/yr and lastly, and seedlings for rubber trees at 1.7 Mton/yr in 2019 (Department of Statistics Malaysia, 2020). The consumption of livestock feed is the second-largest source of inflow, comprising approximately 9% with a flow of 8.8 kton/yr, followed by the use of mineral fertiliser which accounted for 1% of the total input. The outflow of food from the P1 sector is 791 Mton/yr, consisting of 36% contributed by animal products with 284 Mton of food and others (including food and compost fertiliser) at 64% with 508 Mt food.

However, the P1 subsystem is still not considered as fully complete given the low import dependency rate and the rate of waste recycling from plantations in each state. Nevertheless, this subsystem is advantageous in terms of contribution to the Gross Domestic Product (GDP) of 65% for international trade with higher value of agriculture export products as compared to import value, accounting for 55% (RM 114,451 million) and 45% (RM 93,313 million), respectively. This subsystem is considered the most significant contributor to Malaysia's economic growth with a national GDP contribution value of 12%, and 16% to the labour market for Malaysian citizens (EPU, 2020).

The total amount of flow accumulated in the P2 Subsystem is 1216 Mton/yr, which includes feed flow of livestock food, fresh food, frozen food, processed food, eggs, milk, grains, fruits, vegetables, potatoes, seafood products, and so on. If the inflow and outflow of food were compared, then the difference of nine times would be moderately high, which accounts for 562 Mton/yr and 654 Mton/yr respectively. This is because the processing and marketing stages are responsible for the food product demands for most of the livestock commodities (51%) and others (48%), consisting of fisheries, cultivation, and other plantation products. Furthermore, the largest outflow was observed from the main by-product of the food products processing industry which amounted to 385 Mton/yr, with a large portion of food flow (59%) being disposed of directly into landfills such as grain milling, oil cakes, animal fat, skin, blood, hides, and inedible animal organs. Information obtained on the by-products produced by the developers of the food processing industry tends to show values that are either too high or too low, especially on the recorded recycling rate (approximately 25%) of the food flow from the subsystem P4 (waste management) which will eventually re-enter the P2 subsystem, equivalent to 57 kton/yr and contributes to a high level of uncertainty.

Table 3. Intervals of uncertainty with data sources and descriptions (based on Hedbrandt and Sörme, 2001; Danius and von Malmborg, 2002).

Uncertainty level and Coeficient Variation (CV)	Factor	Source of Information	Example in this study
1 and CV 15%	(interval */1.1)	- Official statistics at the national, state and local levels - Information obtained from the authority or the construction party or the production party. - Information obtained from facilities subject to permit conditions	- Production of crop and livestock products as well as fishery products. - Current census of Malaysian population by state. - Total use of seed ore and fertiliser. - Number of households, cars, etc. - Area of agricultural land, number of livestock. - Quantitative content from the national literature
2 and CV: 30%	(interval */1.33)	- Official statistics at the national, state and local levels cover geographical and temporal scales. - Quantities are generally obtained from literature sources. - Data is obtained from the authority or the construction party or the production party.	- Total food consumption per capita per individual. - Percentage of pollutant emissions - Ratio of agricultural biomass products that can be recycled or reused. - Total leachate discharge by territorial boundary.
3 and CV: 45%	(interval */1.5)	- Modeled data for the respective municipalities. - Official statistics at the national level are relegated to the local level. - Information on request from authorities - Scientific literature and technical reports.	- Food stock content - Total production of wet and dry food waste in Malaysia - Different range of gray water and black water. - Total food waste stock according to the study subsystem
4 and CV: 60%	(interval */2)	- Information published by manufacturers or business entrepreneurs - Official statistics at the national and regional levels. - Information obtained at the request of authorities, manufacturers or operators. - Information from the literature review literature with moderate certainty. - Official statistics using the Malaysian scale.	- Use of food raw materials on an annual basis - Literature of the study of different organic waste flows according to the differences of the states in Malaysia. - Food consumption input ratio -import and export of animal feed and dairy products
5 and CV: 75%	(interval */4)	- Generalisation of data is generated from the general literature of the study. - The certainty results are large due to estimates made based on scale values, assumptions, ranges, literary highlights that have no reference or vague approach.	- Percentage of food consumption. - Percentage of sewage discharge from the household, commercial and industrial sectors. - Types of agricultural and food products exported. - The quantity of garbage disposal or use of animal waste that is unofficially recorded

3.1.2. The flow of food in the human consumption subsystem (P3)

The entire inflow and outflow of food for subsystem P3: human consumption were moderately proportional to each item, with 20 Mton/yr and 8.2 Mton/yr, respectively. A large percentage of inflows (91%; 18.2 Mt/yr) entering the household and retail process was from imported and domestically produced crop and livestock products, whereas the remaining 9% (1.8 Mt/yr) was derived from fishery products. Resultantly, excess food outflows (known as food waste flow) contributed to the loss to the environment at 30% (1.9 Mt/yr), as the efficiency rate of food waste disposal at landfills only covered 70% (4.5 Mt/yr) (Hashim et al., 2021). Meanwhile, 12% (1 Mt/yr) of food waste processed as compost fertiliser and other reusable food by-products returned to P1 and P2 subsystems. In addition, the final outflow consisted of faeces and urine, along with domestic wastewater which recorded a percentage value of 33% (27 Mt/yr).

3.1.3. Food flow in waste management subsystem (P4) and waste water management (P5)

The final two subsystems P4: Waste Management and P5: Wastewater Management, are potentially the largest contributors of outflow loss into the environment system, which can be observed by the treatment efficiency rate of material flow final management. Nonetheless, the value reported by using the MFA approach is 99% in Malaysia's case, which refers to the total population receiving maintenance services of waste disposal management and final treatment at wastewater plants. Therefore, such circumstances affect the pattern and quantity of food flows according to different distribution areas. For instance, the low efficiency of organic waste management at the household stage (i.e., the first phase of waste management), especially in states that did not adopt Act 672, had increased the food wastage flow directly to the environment by 38%. The breakdown of the metabolic performance of the current P4 and P5 subsystems is shown in Table 5 while the performance of future scenarios is discussed in Section 3.2.3.

Table 5 shows the trail of food flow within the subsystem P4: Waste management of 392 Mt/yr in 2019. Three prominent trails of food flow were detected entering this subsystem: discarded processed food waste, discarded food waste, and discarded sludge at 99% (385 Mt/yr), 0.8% (4.5 Mt/yr), and 0.2%, (0.9 Mt/yr), respectively. These significant percentage differences indicated that the effect of by-products waste from food processing service category contribute most to the waste disposed directly at landfills. These events could be reduced by modifying the development objective of zero organic waste towards improving the food recycling loop which includes increasing the recycling of food product waste or shifting it to composting process (Mohammad Hariz et al., 2020). At the downstream of waste disposal, the amount of food flow discharge into the environment is the main contributor, amounting up to 89%, followed by compost landfill at 8%, and reused waste by the trading sector at 3%, (Diagram 3). The performance of waste flow that is rich with special bio-organic mixture has the potential to complete the material (or food) recycling through anaerobic digestion, compost consolidation, energy recovery, or conversion in any way to a valuable product for export outside the study system (M.N et al., 2021; Szulc et al., 2021). Nevertheless, other factors such as cost, technology, and socio-culture may affect the efficiency in the governance of food waste recovery, thereby reducing the value-added food loop in the subsystem.

In 2019, all wastewater treatment in Malaysia connects a total of 32.6 million people; amounting to 2.7 Mton/yr while Indah Water Consortium Sdn Bhd (IWK) provides sewage service to almost 25 million people, equivalent to 2.1 Mton/yr of inflow. The remaining population of almost 7.5 million people are managed by local authorities in Kelantan, Sabah, Sarawak, Johor Bahru, and Pasir Gudang, contributing about 0.6 Mton/yr of inflow. However, the amount of this flow is expected to change significantly, as Majaari Services Sdn Bhd, the sole sewerage company in Kelantan, has handed over 100% of the operation and maintenance of their public sewerage system to the federal government in 2021. A detailed measurement of the inflow and outflow of other water managements is also reported in Table 5. For inflows, the ratio between wastewater treatment from connected services and disconnected services sources is 62:38. This led to high percentages of effluent (66%; 1.8 Mt/yr) and sludge discharge (33%; 0.9 Mt/yr) while considering the 1%

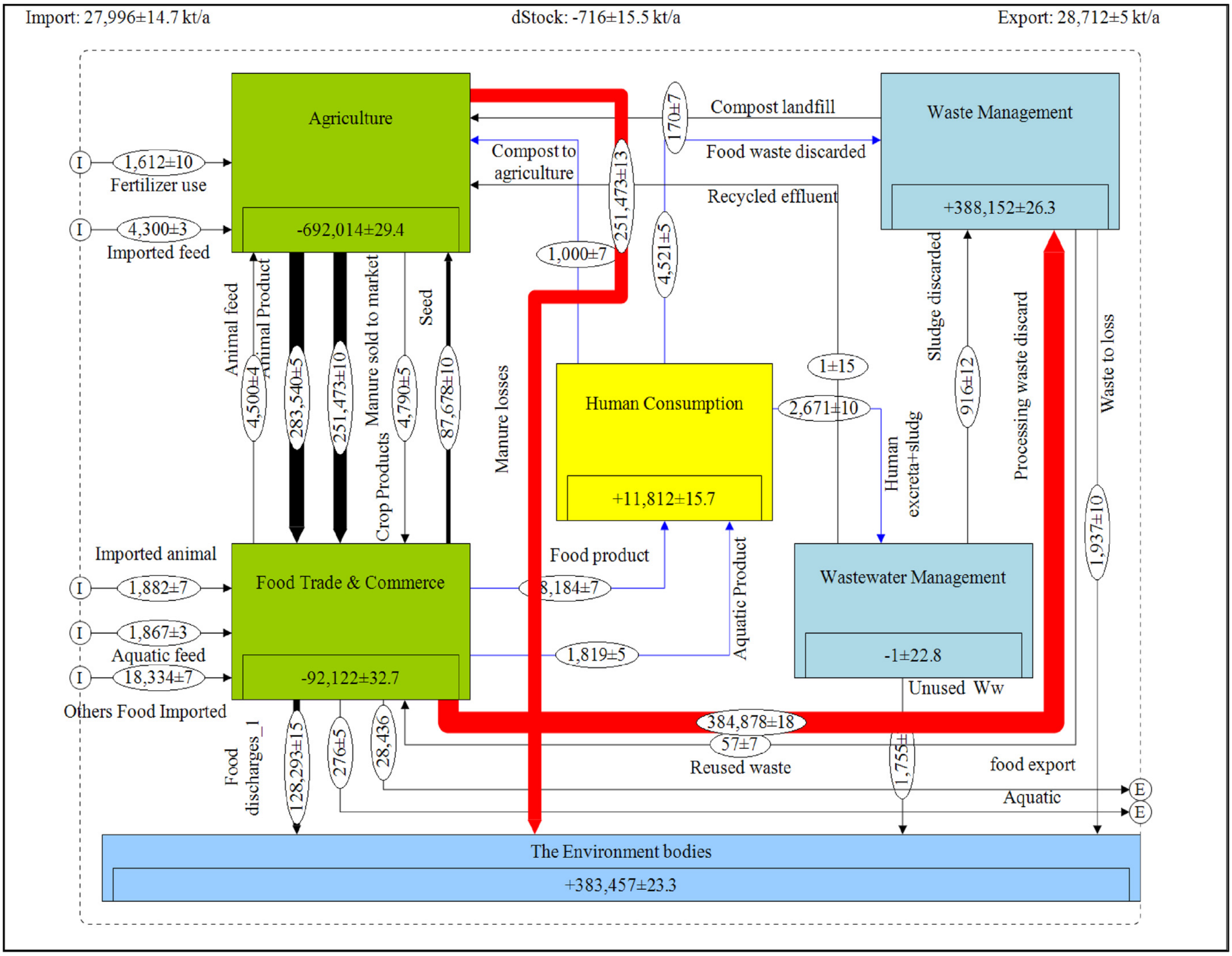

Figure 3. The movement of food flows in various production, consumption, and management subsystems in Malaysia, quantified for 2019 (Units are ktonne per year). (The width of the red arrow indicates the largest flow quantity while the black ones indicate the inflow and outflow quantity of other materials within the system boundary drawn with a dash black line).

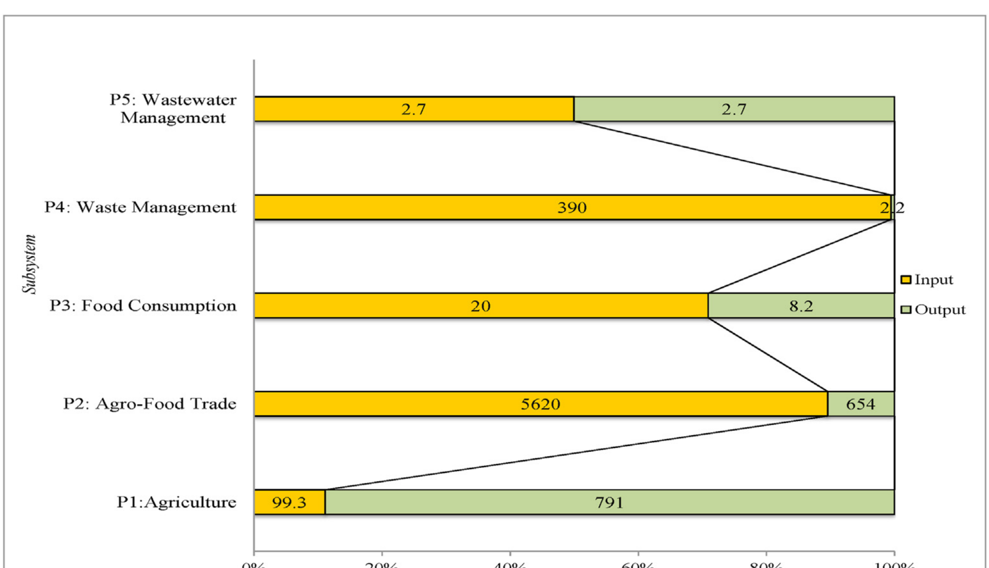

Figure 4. The contribution of inflow and outflow according to subsystem components.

Table 4. Food consumption rate in Malaysia in 2019.

Category	Average Food Consumption (kg/cap/yr)*	Total food consumption (Mton/yr)
Rice	120.9	3.9
Cereals and oats	1.02	0.1
Wheat and products	47.4	1.5
Daging, offals, edible, animals fat, raw, etc.	0.1–50.9	2.1
Eggs	17.9	0.6
Milk-Excluding Butter (in litre)	5.02	0.2
Oilcrops oil and other	0.01–6.68	0.6
Fish	0.22–18.16	1.8
Vegetables	1–46.93	3.1
Fruits	0.2–13.2	2.1
Spices	3.32	0.1
Sugar and sweeteners	0.03–42.2	1.5
Infant food	1.69	0.1

(Source*: FAOSTAT, 2019; Department of Statistics, 2020)

Table 5. Summary of food input and output flows into the waste management and wastewater management subsystems.

System		Description	Efficiency rate	Amount in Mton/yr
P4: Waste management	Inputs	-Food waste sent to landfill: to environment recycle	30% 5%	1.94 0.22
	Outputs	- Household organic waste used for compost - Recycled organic waste for sell	75% 25%	0.2 0.01
P5: Waste water subsystem	Inputs	- Wastewater treated by public sewage plant - Wastewater treated by private sewage plant - Wastewater loads by communal septic tank - Wastewater loads by individual septic tanks - Wastewater loads by flush toilets	54% 8% 2% 23% 14%	1.44 0.21 0.03 0.61 0.37
	Outputs	- Effluent from MBT treatment - Effluent from Non-MBT treatment - Wastewater-sludge from MBT treatment - Wastewater-sludge from non-MBT treatment	100%	761 994 254 663

(0.001 Mton/yr) of the household and retail sectors that have received back the sewage product through processed compost.

A high level of uncertainty involves outflows through food consumption in urban-rural areas that are not released to sewage treatment plants; instead, it is being disposed into natural aquatic systems before being subjected to wastewater treatment. The typical example is the release of wastewater from informal, medium, and small slaughter industries and unregistered with official parties (such as the Veterinary Department and the Department of Environment), in which almost all will end up at the farm site itself. The results corroborate the study of (Abdul Hamid et al., 2017) who highlighted the challenge of inadequate and inefficient management of wastewater disposal, as well as the low-efficiency rate of wastewater treatment in Malaysia, especially in rural areas (Abdul Hamid et al., 2017).

3.1.4. Fa-system modelling as usual

In the scenario of flow equilibrium modelling, two criteria usually form the basis of the system: the extent to which the actual food flow is unknown and unquantified but demonstrates the potential for long-term improvement. For example, the food flow in remote areas or the flow produced by commercial, industry, and institution sectors could affect the actual production-utilisation of agricultural raw materials at the national level, thereby reducing the dependency on other countries. From the perspective of environmental protection, the second criterion is the potential for environmental pollution caused by disruptions to modify or affect the food flow system network. This situation will add pressure to the country's food inventory and security challenges. This is due to the excessive food flow loss potential recorded at upstream (44%), middle (29%), and downstream (27%) levels. This situation is indirectly caused by the COVID-19 pandemic crisis, which is expected to induce a reduction in the nation's food reserve stock in the coming years (Regina et al., 2021; Adnan and Nordin, 2021). Hence, the Malaysian government will launch the National Agrofood Policy 2021–2030 (NAP 2.0) by targeting several key objectives such as increasing the country's food production and supply, increasing access to food, stabilising food prices, and ensuring food and nutrition security (MAFI, 2020).

3.1.5. Fb-use of proxy system at upstream level (P1+P2)

Improving the governance strategy and better policies are the two important measures to close the broken food loop in the P1 and P2 subsystems in the upstream level scenario. These strategies should be targeted at farmers, Small and Medium Enterprises (SMEs), and micro-entrepreneurs. Examples of the policy strategies to minimise food flow loss include the aspects of technology development and innovation, material marketing and network, development of high-value agriculture products and foodservice delivery systems, and food quality and security (MAFI, 2020).

Following the decision in Section 3.1.1, economic-political adjustments that are capable of reducing the total outflow loss of local livestock waste and wastewater by 55% include the labour force income scheme, direct crop diversification, material price, subsidies, complex logistics, and product marketing (97 Mtonne/yr). These strategies could also facilitate recycling and recovery of crop biomass to bioenergy and nutrient production by 15% (79 Mtonne/yr). Meanwhile, consolidation of the socio-technology aspect can change the landscape of the utilisation and supply of agricultural land stock by 23%, resulting in a direct change response on the food supply chain system in Section 3.1.2. The trade sector in the P2 subsystem refers to the 'food from the industry' flow, which includes by-products, mixed foods, net import-export, supplementary food, and others. According to the MYCC (2010), only 10% of the P1 outputs are used in the food processing sector in P2. This scenario is considered to function as a controller of loss and wastage in the country's food flow. For example, dilution of import value at the global level could increase from 58% to 68% in the P2 subsystem. In contrast, the rate of 3/5 for the value of inflows from food and industrial by-products that are not originally from the domestic food (remote) production system provides a strong justification for losing 38%–68% in the value of production deficit for finished food products (Figure 5).

3.1.6. Fc-use of proxy system at middle level (P3)

In the middle-level scenario, this study simulated the effects of increased population, urbanisation, and changes in food usage by users. Factors such as lifestyle changes, living standard improvements, and health awareness are increasingly changing users' eating habits. This scenario estimates that the diversion of food flow into P3 will be 17% in 2030 with twice the total food waste production for P3(-). According to (Ref), easy access to processed food, easy to cook, and easy to eat food such as frozen, fatty, and low-calorie food, coupled with the ability of households to easily make online purchases and sufficient financial resources for daily expenditures will increase the food loss that ends at the downstream level (P3- = P4 ± P5 ± E) (Expand food waste diversion and

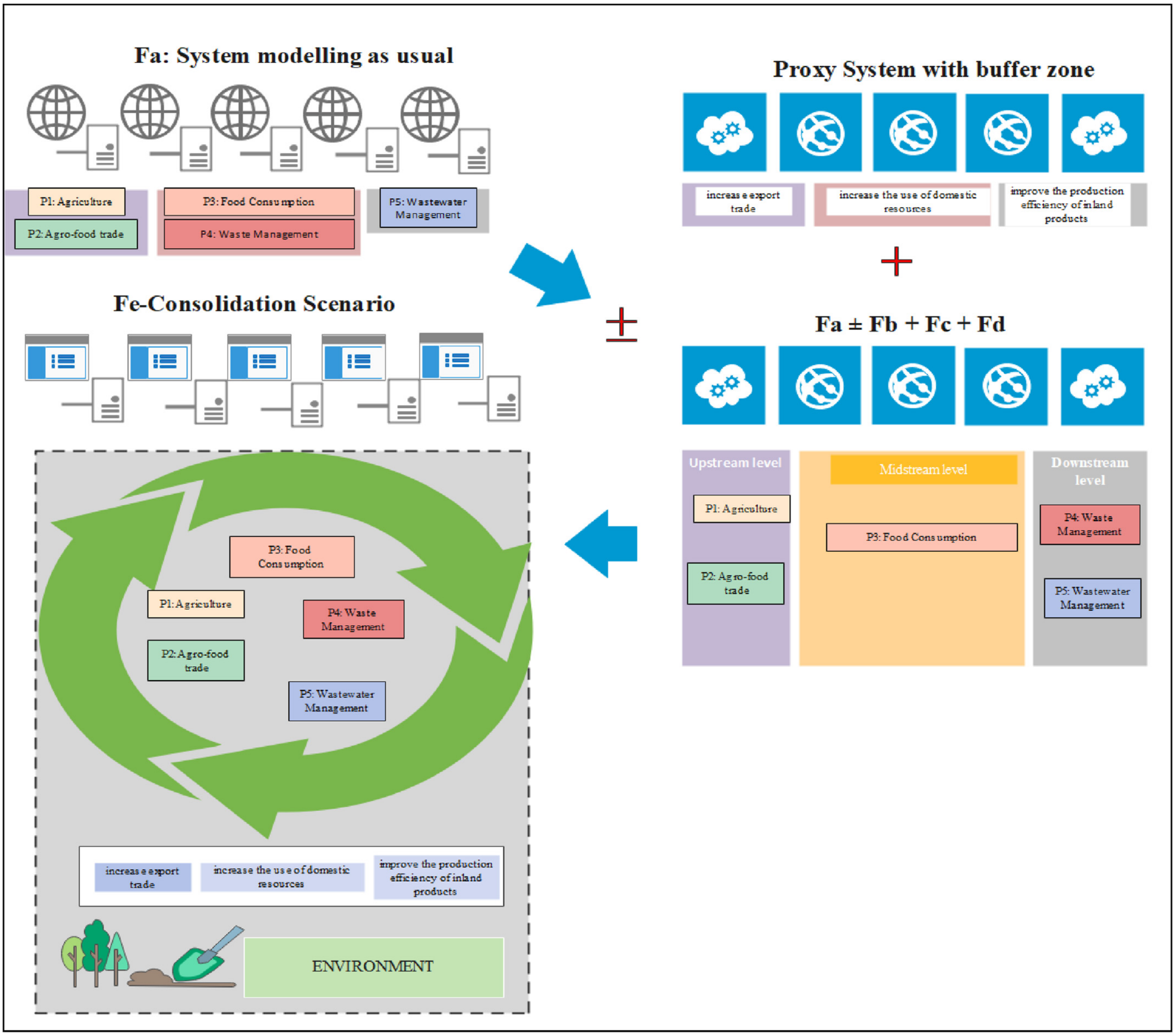

Figure 5. Comparison of the percentage of food flow level in each subsystem. The calculation of the efficiency rate refers to the total food outflows divided by the total food flow that enters the studied subsystem. Four scenarios have been developed, where the initial scenario refers to the current scenario (Fa) in 2020. The second scenario, Fb, shows the use of the proxy system at the upstream level (P1 and P2); Fc is the third scenario, which is the use of the proxy system at the middle level (P3) in 2030; Fd is the fourth scenario, representing the fully used proxy system at the downstream level (P4, P5, E) in 2030; Fe depicts the utilisation of all the proxy systems at all levels: Fa, Fb, Fc, and Fd, which will produce the best solution in sustainable food management in 2030. The details are described in Section 3.2.1 until Section 3.2.5.

recycle wastewater to produce biosolids, biogas and sewage sludge). The results revealed that the recovery measures in P3-middle (stricter rules and broader awareness promotions) can reduce the food flow loss by 40% over the next five years. For instance, enforcement by the Malaysian authorities to prohibit the disposal of organic waste in landfills by 2026 could reduce the pressure at the stage of municipal organic waste collection and food processing infrastructure. Nevertheless, most of the hidden flows, especially food consumption per capita flow in remote areas and the 'zero' background (unofficial and unrecorded data flow) have the most promising effects on stock, waste, and food recycled products reservoir. The Malaysian Government has paid greater attention by promoting the introduction of National Agrofood Policy 2021–2030 (NAP 2.0) , leading to increased use of food flow digital technology in the value-added processing subsystem from 12% to 31% of the total food production after the 21st century (MOA, 2017).

3.1.7. Fd-scenario of proxy system at the downstream level (P4+P5+E)

The downstream scenario is an attempt at recovery, treatment, and diversion of flow which involves the back end (i.e., the production of food waste and sewage or washing water). This scenario need to be resolved so that the alternative of reusing waste or wastewater resources and pollution effects can be reduced across space and time. For example, two-third of the sewage water in urban areas enters the sewerage system while another one-third enters the environment directly without undergoing collection or treatment. This highlights the necessity of controlling the loss of wastewater flow, especially greywater by sending it for treatment and re-use as a secondary source such as sludge or compost. Mea, food waste loss can be reduced drastically in this scenario by ensuring the involvement of stakeholders in increasing the closed-loop recycling for organic waste (excluding garden waste) by 7%–25%, maximising the vegetarian diet, providing recycling technology services, and reducing the importation of food. On the other hand, the waste management scenario involves the outflow of leachate dissolved in landfills with organic and inorganic substances, as well as the emission of methane (CH_4), carbon dioxide (CO_2), Nitrogen (N_2), and oxygen (O_2) gases and other compounds (Neskovic et al., 2019). Therefore, presumably, the efficiency of pre-filtration, collection, and recovery of waste flows to biomass sources and other green products is higher than each of the Fa±, Fb±, and Fc ± scenarios. As shown in Table 5, the food outflow can be reduced by 39% and the total stock of food waste assumed to remain in the landfill is around 84%–87% with a gas emission of 10% and leaching of 3%–6% (Neskovic et al., 2019).

3.1.8. Fe-consolidation scenario (Fa + Fb + Fc + Fd)

The consolidation scenario (Fe) combines all phases where the structural adjustment of the food flow network has to be resolved across broader and cross-layered food disciplines. An example is the social-ecological approach with two-way layering through bottom-up and up-bottom by the MFA food system players. Additionally, the integrated socio-technology approach (Bui, 2021) may be used in value-added processing management for agricultural and agro-waste products through the flow track along the upstream middle and downstream chain. High savings of food flow loss could result from increased usage of technology and management approaches through the application of methods of nexus-water, energy, food (WEF) (Golam and Bikash, 2016), industrial symbiosis (Neves et al., 2019), and industrial ecology (IE) (Kendall and Spang, 2020).

The introduction of agro-based food industry strategy by the National Agrofood Policy (NAP) (MAFI, 2011), using the formulation to Scenario Fe could support sustainable food flow management. The solution in this face should encompass the optimisation of the availability of food resources in the future. This could be achieved by ensuring that the useful regional or territorial stocks have the self-sufficiency and survivability to support production when barriers arise in terms of interrupted importation and exportation or internal pollution. Table 6 shows a comparison of the percentages of total stocks and food waste recovery (secondary source potential), which are expected to increase by 38% and 71% for the Fe scenario, compared to other scenarios such as Fa: 12% and 21%, Fb: 17% and 29%, Fc: 28% and 40%, and Fd: 30% and 49%. Notwithstanding, domestic losses could still occur with an expected percentage of 20%–50% if the ideal management efficiency rate decreases and the spread of pollution points increases.

3.2. Limitations and uncertainty analysis

Several variables emerged in this study due to some unobservable or uncountable flows and those that were difficult to detect due to their annual variation in the MFA model. The comparison covering five MFA subsystems revealed that the data reconciliation and deviation responses contributed 11%, which occurred in the trade subsystem. This increase was caused mainly by the relatively high uncertainty relating to the internal-external flows in the import-export trade sector for food processing products, finished food products, and raw food products at domestic and international levels. Table 7 summarises the uncertainty contributions from other subsystems and the uncertainty error was usually associated with model uncertainty and data uncertainty (Huijun et al., 2016). A total of 9 sets of variables were identified as contributing to low-quality data points while 14 sets of variables with a significant effect resulted from model unsuitability. Nevertheless, the best representation of the flow system model findings, more accurate and refined results, and reliability were obtained by modifying the results of a set of data variables and combining them with another appropriate model simultaneously.

Data review and data source cross-examination, data arrangement, data suitability, and data fitness make up the data uncertainty criteria. Increasing the use of high-quality and rational data point content by 10% will lead to a change of 47%–78% in the final result calculated in this study. For instance, using the best quality and quantity content, the intensity of the annual food flow released into landfills and sewage treatment plants based on the local literature for the last three years has a higher, more robust, and stronger impact. The present study employed statistical references from the annual book of Department of Statistics Malaysia and the FAOSTAT website for the overall food management metabolism investigation, ignoring the effects by regional and geospatial variations and the extrinsic estimation inventory, such as productivity effect, environmental effect, the economy, the socio-political landscape, and so on. For example, this study focused only on the discussions and solutions relating to the techno-environmental field perspective, thereby failing to address the interventions of socio-economic and political factors on the environmental impacts, such as the behaviour-activities of food users, the food governance system, the stakeholders' social network, and others. As such, hybrid approaches such as Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA), Social Network Analysis (SNA), and supporting tools that produce other results are recommended to obtain more complete, holistic, and accurate food flow information.

Two main trends emerged in the model uncertainty analysis (Table 4). Firstly, the main food flow tends to only consider the system-related aspect. Secondly, the input-output flow estimation for the macro scale has been used more than the micro-scale, thus ignoring the matters possessing spatial and temporal structural characteristics for the MFA model. Based on the reports from a previous study on waste management (Ghani, 2021), the current study also developed a single MFA model, which has caused significant uncertainty about the model. It is important

Table 6. Proposal to develop an MFA proxy model system scenario simulation.

Structural improvement and adjustment indicators	Scenario Fa (original)	Scenario Fb (change at upstream level)	Senario Fc (changes in the middle level)	Scenario Fd (changes at downstream)	Scenario Fe = Fa + Fb + Fc + Fd (Integration of all scenarios/combinations)
Flow deficit-loss scenario	No flow change. The flow is considered permanent at 100%	Flow loss of 44%	Flow loss of 29%	Flow loss of 27%	Flow loss is considered to be less than 5%
Food waste recovery option: - recycle - Integrated waste and wastewater treatment technology - Practice Principle 4R - Good governance for the food system		- 70% of manure losses *251 Mton/yr) = 176 Mton/yr - Introduction of an endogenous agricultural sector model	- Developing a social business model: innovative technology + corporate strategy + expert knowledge	- Promotion of recycling of crop, livestock and food waste products, sludge and effluent. - Develop technical skills and improve food management infrastructure	- Economic recovery of food waste - Recycling of wastewater and food waste - Stakeholder collaboration in food system management support decision-making
Reserve stock		The accumulation of food flow is greater			The accumulation of food flow remains balanced
Trade - Import - Export		The export value of agro-food products exceeds the value of imports	The export value of agro-food products exceeds the value of imports	None	>7% of food waste is traded abroad

Table 7. Uncertainty analysis results; effect of changes of 5%–15% in the 34 variables that emerged for the main results of the overall food flow management system. All values are in percentage [%].

Types of uncertainty	Variables	Sensitivity value
Data uncertainty	Garbage flow, urban wastewater flow, runoff flow, use of crop fertilisers, meat and dairy production, crop production, food waste generation, feedstuffs exported	8%–14%
Model uncertainty	Loss of soil erosion, livestock inputs, plantation inputs, population consumption, food purchase inputs, per capita consumption of food types, waste treatment facilities, import and export of food commodities, food processing, import and export of crop products, human waste production content, other factors- other additions; human resources, time and financial costs.	5%–31%

to estimate the inflow, outflow, and total stored in each subsystem according to the sequence of years to obtain a higher absolute value of the food flow equilibrium. Using the assumption from Chowdhury et al. (2016), the basic value of model uncertainty is highly dependent on the quality of the input data, whether involving a systematic data collection procedure or otherwise. Furthermore, micro-level data from the local and focused context will facilitate the usage of high sensitivity accuracy in the MFA model. An example is the application of mathematical equations relating to the MFA model coefficients to calculate the total food consumption by the Malaysian population, which follows the average age range is more accurate than using the gross average quantity of food consumption per capita by the Malaysian population. Conclusively, further research is necessary to analyse the food flow metabolism based on the saying, "there's no smoke without fire", meaning that both implicit and explicit types of information will significantly impact the final research findings.

4. Conclusion

This article presented the interactions of inflows, outflows, and food stocks in the core sectors including the agricultural system, which were analysed based on data availability for Malaysia in 2020. This study has also highlighted intervention strategies and recommendations to reduce the vulnerability in the country's food supply chain management. Several key issues have been successfully explored further, including (1) interventions using food recovery socio-technology, (2) diversion of food flow with demand-side shifts in food demand, food patterns, and food waste management, and (3) potential expansion of the coalition of actors in decision making. The research findings revealed that profits and losses formed from the shifts in food flow vary according to the studied subsystems with the total food equilibrium reaching 2,533 Mt per year in 2020, whereas 25 key indicators were identified with the mean total food stored of 63%. The eight components of the potential improvements for the circular economy category are: 1) 4R legal framework, 2) government involvement, 3) use of integrated technology, 4), integrated agriculture system practices, 5) new business models, 6) guidelines for local implementation, 7) alternative solutions, and 8) improvement of the interaction between agents and systems. In summary, the aspects of confirmation of the pollution risk, food recovery efficiency, and reducing the dependency on food product importation from international markets remain the missions of transition in Malaysia for the foreseeable future. Based on the analysis of current times and projected future scenarios, this study contributes originally to the stakeholder practitioners in driving the sustainable food system management strategy. Conducting research using the socio-ecology concept (i.e., cause-effect analysis) encompassing different actors along the food supply chain could elucidate the issues and impacts in food supply management. Future testing of the following types of intervention to the MFA framework could support the agenda of promoting the NAP Malaysia and can also be applied at the global level to achieve the sustainability of the sustainable development agenda. Additionally, by selecting 'food' as the study material, this article helps remarkably in diverting the other researchers' attention by adopting the MFA approach to understand the dynamics of other material flow. This study also identified the relationships between resources, economic models, and integrated technologies to increase the level of material management efficiency, extend community survival, protect the environment, and restore resources for long-term management.

Declarations

Author contribution statement

Latifah Abdul Ghani: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Noor Zalina Mahmood: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Roslina Ismail; Siti Aisyah Sa'at; Nora'aini Ali; Siti Aishah Mohd Zakuan: Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported with funding from the Malaysia Ministry of Higher Education (MoHE) with code of FRGS/1/2020/SS0/UMT/03/1.

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no competing interests.

Additional information

No additional information is available for this paper.

References

Abdul Hamid, Mohd Fairuz, R., Nor, Azuana, Elias, Z., 2017. Energy efficiency strategies for sewage treatment plant: a Case Study in Malaysia. In: International Conference on Engineering Technology and Technopreneurship (ICE2T), pp. 1–5.
Adnan, N., Nordin, S.M., 2021. How COVID 19 effect Malaysian paddy industry? Adoption of green fertilizer a potential resolution. Environ. Dev. Sustain. 23, 8089–8129.
Ahmad, I., Chelliapan, S., Abdullah, N., Ahmad, M., 2019. Sanitary landfill is a solution in solid waste management or a silent threat to environment: Malaysian scenario. Open Int. J. Inform. (OIJI) 7, 135–146.
Ahmad Rizal, A., Latifah, A.G., Amir Hamzah, S., 2019. The flow of phosphorus on dairy cattle livestock by using material flow analysis (Mfa) in taman pertanian Universiti putra Malaysia. In: Selangor, Faradiella, M.K., Normala, H. (Eds.), Socio-Ecological Prospects, in: Environmental Studies Vol 2. UPM Serdang. UPM Press.
Alias, E., Radam, A., Fen, Y., Yacob, M., Alam, M.F., 2014. Growth in Malaysia's export food market: a shift-share analysis. Asian Soc. Sci. 10, 26.
Amy, M., Pete, S., Terence, P.D., 2021. Impacts of land use, population, and climate change on global food security. Food Energy Secur. 10, e261.
Bank Negara, 2020. The BNM Quarterly Bulletin. Malaysia. https://www.bnm.gov.my/. accessed 10 March 2020.
Brunner, P.H., Rechberger., H., 2016. Practical Handbook of Material Flow Analysis, 2nd edition. CRC Press.
Bui, S., 2021. Enacting transitions-the combined effect of multiple niches in whole system reconfiguration. Sustainability 13 (11), 6135.
Chen, H.L., Nath, T.K., Chong, S., et al., 2021. The plastic waste problem in Malaysia: management, recycling and disposal of local and global plastic waste. SN Appl. Sci. 3, 437.
Chin, P.M., Naim, A.N., Suja, F., Ahmad Usul, M.F., 2020. Impact of effluent from the leachate treatment plant of taman beringin solid waste transfer station on the quality of Jinjang river. Processes 8 (12), 1553.
Chowdhury, R.B., Moore, G.A., Weatherley, A.J., Arora, M., 2016. A novel substance flow analysis model for analysing multi-year phosphorus flow at the regional scale. Sci. Total Environ. 572, 1269–1280.

Danius, L., 2002. Data Uncertainties in Material Flow Analysis: Local Case Study and Literature Survey. Royal Institute of Technology, Stockholm, Sweden.

Danius, L., von Malmborg, F.B., 2002. On the Treatment of Uncertainty in MFA: a Literature Survey. Unpublished.

Department of Statistics Malaysia, 2020. Malaysia External Trade Statistics Bulletin, September 2020. Department of Statistics Malaysia. https://dosm.gov.my/. accessed 10 May 2020.

Emiko, F., Will, M., 2020. Economic growth, convergence, and world food demand and supply. World Dev. 132, 104954.

Ghani, L.A., 2018. Potential use of Substance Flow Analysis to recount the nitrogen flux in agriculture soils system in Terengganu. J. Eng. Sci. Technol. 14 (3), 1289–1300.

Ghani, L.A., 2021. Exploring the Municipal Solid Waste Management via MFA-SAA Approach in Terengganu, Malaysia. Environmental and sustainability indicators 12, 100144.

Golam, R., Bikash, S., 2016. The nexus approach to water–energy–food security: an option for adaptation to climate change. Clim. Pol. 16 (6), 682–702.

Haikal, I., Marlia, M.H., 2021. Evaluation of e-waste management systems in Malaysia using life cycle assessment and material flow analysis. J. Clean. Prod. 308, 127358.

Hashim, A.A., Kadir, A.A., Ibrahim, M.H., Halim, S., Sarani, N.A., Hassan, M.I.H., Hamid, N.J.A., Hashar, N.N.H., Hissham, N.F.N., 2021. Overview on food waste management and composting practice in Malaysia. AIP Conf. Proc. 2339, 020181.

Hedbrandt, J., Sörme, L., 2001. Data vagueness and uncertainties in urban heavy metal data collection. Water Air Soil Pollut. Focus 1, 43–53.

Heikal, I.M., Ghazi, T.I.M., Hamzah, M.H., Manaf, L.A., Tahir, R.M., Mohd Nasir, A., Ehsan, O.A., 2020. Impact of movement control order (MCO) due to coronavirus disease (COVID-19) on food waste generation: a case study in Klang valley, Malaysia. Sustainability 12 (21), 8848.

Huijun, W., Yongliang, Z., Zengwei, Y., Liangmin, G., 2016. A review of phosphorus management through the food system: identifying the roadmap to ecological agriculture. J. Clean. Prod. 114, 45–54.

Iona, Y.H., Louise, M., Katy, L.J., Vasilis, G., Anthony, M., Victoria, W., Shane, W., 2021. Food waste management: a review of retailers' business practices and their implications for sustainable value. J. Clean. Prod. 285, 125484.

Irmeline, d.S., Helge, B., Pieter, C., 2020. Waste prevention, energy recovery or recycling - directions for household food waste management in light of circular economy policy. Resour. Conserv. Recycl. 160, 104908.

James, C., Cynthia, C.-M., 2013. A substance flow analysis of phosphorus in the UK food production and consumption system. Resour. Conserv. Recycl. 74, 82–100.

Kendall, A., Spang, E.S., 2020. The role of industrial ecology in food and agriculture's adaptation to climate change. J. Ind. Ecol. 24, 313–317.

Latifah, A.G., Noor Zalina, M., Faridah, O., 2019. Assessment of phosphorus load in water river uisng substances flow analysis (SFA). J. Eng. Sci. Technol. 14, 1289–1300.

Laura, G.-H., Christine, C., Fabio, D.M., Lydia, S., Matteo, V., 2021. Eating away at sustainability. Food consumption and waste patterns in a US school canteen. J. Clean. Prod. 279, 123571.

Malaysia Competition Commission: MYCC, 2010. Market Review of Food Sector in Malaysia under the Competition Act 2010. Malaysia. https://www.mycc.gov.my/. (Accessed 5 January 2021). accessed.

Maryegli, F., Raphael, T.V.B., Witold-Roger, P., 2021. The role of a socio-integrated recycling system in implementing a circular economy – the case of Belo Horizonte, Brazil. Waste Manag. 121, 215–225.

Ministry of Agriculture and Food Industries (MAFI), 2011. Dasar Agromakanan Negara 2011-2020. Ministry of Agriculture and Agro-Based Industry, Putrajaya, Malaysia. https://www.mafi.gov.my/. (Accessed 6 January 2021). accessed.

Ministry of Housing and Local Government: MHLG, 2021. Ministry of Housing and Local Government Database. https://jpspn.kpkt.gov.my/index.php/pages/view/202/. (Accessed 5 January 2021). accessed.

Mohammad Hariz, A.R., Tosiah, S., Aimi Athirah, A., Intan Nadhirah, M., Masnira, M. Yu., Hasliana, K., Nur Alyani, S., Mohamad Abhar, A.H., Rashidah, A.M., 2020. Inventory and composting of yard waste in Serdang, Selangor, Malaysia. Heliyon 6 (7).

Muhd Adib, B.Y., Nor Ashikin, A., Siti Rohana, M.Y., Farah Ayuni, S., 2021. An urban metabolism and ecological footprint assessment of Shah Alam, Malaysia. Malaysian J. Med. Health Sci. 17, 267–273.

Neskovic, M., Stevanovic Carapina, D., Bjelic, D., Stojanovic, B.L., Ilic, P., Sobot Pesic, Z., Kikanovic, O., 2019. Using material flow analysis for waste management planning. Pol. J. Environ. Stud. 28 (1), 255–265.

Neves, A., Godina, R.G., Azevedo, S., Pimentel, C., C, O., Matias, J., 2019. The potential of industrial symbiosis: case analysis and main drivers and barriers to its implementation. Sustainability 11 (24), 7095.

Nur Rahishahanim, S., Norashikin, A.K., 2021. Establishment of material flow analysis (MFA) for heavy metals in a wastewater system. Ain Shams Eng. J. 12 (2), 1407–1418.

Paritosh, C., Deshpande, Gaspard, P., Helge, B., Annik, M. Fet., 2020. Using Material Flow Analysis (MFA) to generate the evidence on plastic waste management from commercial fishing gears in Norway. Resour. Conserv. Recycl. X 5, 100024.

Patrício, J., Kalmykova, Yuliya, R., Leonardo, L., Vera, 2015. Uncertainty in material flow analysis indicators at different spatial levels. J. Ind. Ecol. 19 (5), 837–852.

Radin, R.B.F., Mou, L.T., Siti Rahyla, R., Mahinda, Senevi, G., Sandra, R.C., 2020. Paddy, rice and food security in Malaysia: a review of climate change impacts. Cogent Soc. Sci. 6, 1.

Regina, G.A., Neilson, I.M., Swee-Kiong, W., 2020. Implications of covid-19 pandemic on household food security: experience from Sarawak, Malaysia. Int. J. Bus. Soc. 22 (1), 1–13.

Regina, G.A., Neilson, Il.M., Swee-Kiong, W., 2021. Implications of covid-19 pandemic on household food security: experience from Sarawak, Malaysia. Int. J. Bus. Soc. 22 (1), 1–13.

Robin, H., Mario, G., Kent, M., Sean, S., 2021. Assessing the circularity of nutrient flows related to the food system in the Okanagan bioregion, BC Canada. Resour. Conserv. Recycl. 174, 105842.

Sallehuddin, S.M., Ambak, R., Othman, F., et al., 2021. Sodium intake assessed by 24-h urine excretion and its relationship with anthropometric measurements in Malaysian adults. J. Health Popul. Nutr. 40, 9.

Schwab, O., Rechberger, H., 2018. Information content, complexity, and uncertainty in material flow analysis (april 2018). J. Ind. Ecol. 22 (2), 263–274.

Shafie, F.A., Omar, D., Karuppannan, S., Shariffuddin, N., 2016. Urban-scale material flow analysis for cities in greater Kuala Lumpur, Malaysia. Proc. Soc. Behav. Sci. 234, 424–433.

Shafie, F.A., Mohd Aris, M.F., Karuppannan, S., Masngut, M.I., Md Rashid, R.I., Ishak, A.R., 2020. Metabolism of Shah Alam, Klang and Petaling Jaya: Insights from Material Flow Analysis, 2. Healthscope: The Official Research Book of Faculty of Health Sciences, UiTM.

Smit, A.L., van Middelkoop, J.C., van Dijk, W., et al., 2015. A substance flow analysis of phosphorus in the food production, processing and consumption system of The Netherlands. Nutrient Cycl. Agroecosyst. 103, 1–13.

Stanisavljevic, N., Brunner, P.H., 2014. Combination of material flow analysis and substance flow analysis: a powerful approach for decision support in waste management. Waste Manag. Res. 32 (8), 733–744.

Sulaiman, N., Yeatman, H., Russell, J., Law, L.S., 2021. A food insecurity systematic review: experience from Malaysia. Nutrients 13 (3), 945.

Szulc, W., Rutkowska, B., Gawroński, S., Wszelaczyńska, E., 2021. Possibilities of using organic waste after biological and physical processing—an overview. Processes 9 (9), 1501.

Yaacob, N.N.F., Abd Manaf, L., Ash'aari, Z.H., 2019. Quantifying the organic waste generated from the fresh market in Kunadasang town, Sabah. Plan. Malaysia 17, 10.

MAFI, 2020. Draft-National Agrofood Policy 2021-2030. Ministry of Agriculture and Agro-Based Industry, Putrajaya, Malaysia. https://www.mafi.gov.my/. (Accessed 5 January 2021) accessed.

MOA, 2017. Ministry of Agriculture and Agro-based Industry, Malaysia. National Agro-Food Policy (NAFP) (2011–2020).

EPU, 2020. Malaysia Economic Planning Unit. https://www.epu.gov.my/en. (accessed 10 May 2020).